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A Microcomputer-Modified Electrical Aerosol Analyzer

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JOURNAL ARTICLE

A MICROCOMPUTER-MODIFIED ELECTRICAL AEROSOL ANALYZER

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Abstract – A commercial electrical aerosol analyzer has been modified through addition of a digital voltmeter, a microcomputer and a printer. In unattended operation the system can acquire a differential particle size distribution, print and plot the resulting spectrum in any of three possible representations, and repeat the cycle at preselected intervals.

INTRODUCTION

The electrical aerosol analyzer (EAA) has become a popular instrument for measurement of submicron aerosol size distributions since its commercial introduction in 1967. By exploiting the known dependence of electrical mobility on particle size, such instruments permit the real time measurement of aerosol particle size over at least two decades of the size range below 1 μm. While the importance of the EAA to aerosol studies is well recognized there remain features of the EAA which could be improved. Of particular concern in the present commercial version (Model 3030, TSI Inc.)* is the need for an operator to manually record the sequence of electrical currents produced during the instrument's measurement cycle and then to perform a series of arithmetical steps which convert the currents to the corresponding aerosol size spectrum.

To solve this limitation the EAA could be supplemented with a minicomputer and related peripherals to perform data input, reduction and output functions. Such a system, however, is relatively expensive and less portable than may be desired. In the following we show that the same objective can be accomplished by means of a microcomputer-based addition to the EAA. The addition consists of unmodified commercial components including a $180 microcomputer, a digital voltmeter, a teletypewriter or equivalent, and an optional audio cassette recorder (a well-equipped laboratory may already possess some of these instruments). In unattended operation the resulting system is able to (1) acquire a differential size distribution over 10 intervals of equal logarithmic size between 0.0032 and 1 μm dia.; (2) print and plot the distribution directly in a number, surface or volume representation; and (3) repeat the cycle indefinitely at a selectable frequency.

The present system is a natural extension of earlier work concerned with improving the utility of an optical aerosol particle counter through microcomputer modifications (Lewis and Lamothe, 1978) and (Lewis, 1978). The same microcomputer has been used in both cases, and the hardware and software organization of the two systems show many similarities.

SYSTEM DESCRIPTION

Hardware

A block diagram of the assembled system is shown in Fig. 1. The unmodified EAA consists of the two components shown within the broken box – the aerosol analyzer itself and its control module. In operation the control module causes the analyzer to generate a fixed time sequence of internal electric fields during a 2 min cycle. Aerosol entering the analyzer first becomes electrically charged and then is subjected to the particular electric field present at

* Mention of commercial products or company names does not constitute endorsement by the U.S. Environmental Protection Agency.

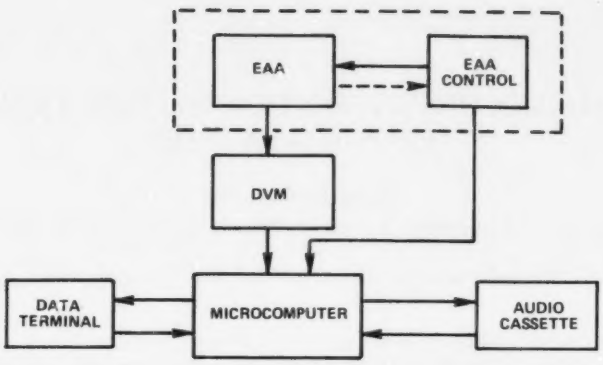

Fig. 1. Aerosol system block diagram.

the time of passage. Depending on the magnitude of the electric field only those aerosol particles larger than a minimum size are able to pass through the analyzer and contribute to a measureable aerosol current ("analyzer current"). Normally the control module is the component that measures the analyzer current sequence (whose values constitute the basic data output of the EAA) and presents the measured values visually to the operator. In the modified system, however, the current measuring and recording functions are performed by the additional components shown in Fig. 1 outside the broken box. Each of these components is described below.

1. *Digital voltmeter (DVM).* The analyzer currents, available at an external coaxial connector on the EAA, are fed directly to the input of a laboratory DVM (although the signal of interest is referred to as a current, the EAA actually converts it internally to a voltage). The DVM is conventional in all respects, but it must have the following capabilities (1) a resolution of at least $3\frac{1}{2}$ digits, with a full scale reading of at least ± 1 V and (2) a binary coded decimal (BCD) output, generating normal TTL positive-true voltage levels. The BCD output is a common interface type that at least some DVM manufacturers provide as an option for their instruments. It is unfortunate that the DVM used in the EAA control module does not have this capability, since there would then have been no need for an additional DVM. Because of availability the particular instrument used in this study was the digital multimeter Model DMM51 (Cimron, Inc.)

2. *Microcomputer.* A KIM-1 microcomputer (Commodore/MOS, Inc.) was used to control the following: acquisition of analyzer currents from the DVM, arithmetical manipulation of the current values and output of the computed aerosol size distribution spectrum. The KIM-1 comprises all the elements of a full-fledged computer (a central processing unit, memory and input–output interface circuitry), assembled on a single 21×26 cm printed circuit board. Details of the microcomputer have been described in earlier work (Lewis and Lamothe, 1978).

The connections between the microcomputer and the other system components are shown schematically in Fig. 1. The microcomputer and DVM are joined by a 16-conductor connection (14 data inputs for $3\frac{1}{2}$ binary coded digits and polarity, a "data ready" input and a ground line). The microcomputer and EAA control are joined by a connection between the interrupt request input of the former and the "read" terminal (negative-true logic selected by internal jumper) of the latter, in addition to a ground connection. Finally, two 4-line connections link the data terminal and audio cassette to the appropriate microcomputer ports.

All connections are simple passive ones, since all active circuitry that the microcomputer requires to transfer information to and from the indicated devices is an integral part of the microcomputer itself.

3. *Data terminal.* A serial 20 mA current loop interface is an integral part of the KIM-1 microcomputer. Thus, the most obvious choice for an output device is a conventional teletypewriter, because of its frequent availability in laboratories. However, newer teletype-

writer "equivalent" devices are attractive on the basis of competitive cost, compactness, quietness and higher speed operation (the microcomputer will operate up to at least 1200 baud). One example that has proved satisfactory in operation with the present system is the Model 743 data terminal (Texas Instruments, Inc.).

4. *Audio cassette recorder.* The KIM-1 microcomputer program which operates the system of Fig. 1 is stored in volatile memory. This means that whenever the microcomputer power is switched off the program is lost and must be reloaded before the next use. The only function of the audio cassette recorder is to provide a convenient means of performing the load operation. Many inexpensive cassette recorders exist that are suitable for this use. A cassette recorder is unnecessary of course if a teletypewriter with paper tape punch and reader is chosen as the data terminal, since the program may then be loaded from paper tape.

Software

The preparation of the microcomputer program constituted most of the system development effort. The program is organized into three segments: acquisition, transformation and output – each of which is described below. The program is available in the form of both a listing and as a punched paper tape upon request.

1. *Acquisition.* The acquisition segment transfers a DVM reading to the microcomputer memory upon command. The EAA control module sends the command via its "read" signal which is received on the interrupt request line of the microcomputer. This causes the "data ready" line from the BCD output of the DVM to be repeatedly scanned by the microcomputer until the appearance of a signal on this line indicates that a new DVM measurement value is available (typical DVM measurement frequencies are several per second). Fourteen data bits, representing $3\frac{1}{2}$ binary coded digits and algebraic sign, are then immediately transferred to the microcomputer memory for storage and the microcomputer awaits the next "read" signal. The end of the EAA measurement cycle is recognized by the number of "read" signals which have occurred.

2. *Transformation.* Upon completion of an EAA cycle the transformation segment of the program performs the same set of computations that an operator normally would to calculate the aerosol size distribution. That is, successive stored readings are subtracted and the differences are multiplied by a set of pre-stored transformation constants. Any one of three sets of constants may be selected, corresponding to the aerosol size distribution expressed in a number, surface or volume representation. The transformation constants given in Table 1 were taken from the (inverse) sensitivities for monodisperse aerosols tabulated by Liu *et al.* (1976). This tabulation is a "smoothed" version of earlier sensitivity data given by Liu and Pui (1975) and judged to be a slightly more realistic calibration than that provided by the earlier unadjusted data. The values in Table 1 and those of Liu *et al.* (1976) differ by a factor 4 because the quantity $\Delta \log D$ is incorporated into the values of Table 1.

Table 1. Transformation factors for number, surface and volume representation of EAA measurements

D (μm)	$\Delta N/\Delta \log D\Delta v$ ($cm^{-3} V^{-1}$)	$\Delta S/\Delta \log D\Delta v$ ($\mu m^2 cm^{-3} V^{-1}$)	$\Delta V/\Delta \log D\Delta v$ ($\mu m^3 cm^{-3} V^{-1}$)
0.00422	0.130×10^{10}	0.720×10^{5}	0.504×10^{2}
0.00750	0.344×10^{8}	0.608×10^{4}	0.760×10^{1}
0.0133	0.140×10^{7}	0.780×10^{3}	0.173×10^{1}
0.0237	0.716×10^{6}	0.127×10^{4}	0.500×10^{1}
0.0422	0.368×10^{6}	0.206×10^{4}	0.145×10^{2}
0.0750	0.189×10^{6}	0.334×10^{4}	0.417×10^{2}
0.133	0.972×10^{5}	0.540×10^{4}	0.120×10^{3}
0.237	0.496×10^{5}	0.880×10^{4}	0.346×10^{3}
0.422	0.255×10^{5}	0.143×10^{5}	0.100×10^{4}
0.750	0.131×10^{5}	0.231×10^{5}	0.289×10^{4}

Fig. 2. Result of an ambient indoor aerosol measurement, illustrating tabular and histogram outputs. The first column lists the average particle diameter (in μm), while the second and third columns give the corresponding volume distribution values $\Delta V/\Delta \log D$ (in $\mu m^3\,cm^{-3}$) as a fraction and power of 10, respectively.

During the subtraction step two cases of invalid data are recognized by the program: (1) an over-range reading from the DVM, and (2) a DVM reading larger than the preceding one. In either case the content of the affected size intervals will be arbitrarily set to zero by the program. Since the effect of an over-range condition on the BCD output will vary with the manufacturer, a programming change may be necessary depending on the DVM used. Similarly some manufacturers may reverse the normal convention that a positive DVM reading sets the sign bit of the positive-true BCD output. The program can accommodate these changes and the simple remedies are included with the program listing.

3. *Output*. The transformed data are printed on the teletypewriter (or equivalent) in a table that lists the 10 values of average particle diameter and the value of the aerosol number, surface or volume (in 4-place floating point decimal form) corresponding to each diameter. The table is preceded by a character (N, S or V) which identifies the choice of representation for the aerosol size distribution. A histogram plot is printed simultaneously with the numerical results as a visual aid. Figure 2 shows a sample output of a volume distribution measurement of indoor air. The first column gives the particle diameter D (in μm). The second and third columns give the corresponding volume distribution values $\Delta V/\Delta \log D$ (in $\mu m^3\,cm^{-3}$) as a fraction and power of 10, respectively.

With a teletypewriter operating at only 10 characters sec^{-1}, a print out generally cannot be completed before the first DVM reading must be taken in the next EAA cycle. The interrupt structure of the program solves this problem automatically by temporarily suspending output until the DVM reading has been taken.

Data are accumulated automatically and continuously from one EAA cycle after another by the microcomputer program. The operator, however, can choose beforehand to print only one of every N cycles, where N is variable between 1 and 255. Thus, a frequency of measurement is possible from once per 2 min to once per $8\frac{1}{2}$ h.

DISCUSSION

The principal advantages of the microcomputer-modified EAA system are the convenience of unattended operation and the immediate availability of the measurement results in the desired units. At the same time two limitations of the system in its present form should be recognized. First, the modified system acquires data with only $3\frac{1}{2}$ digit resolution compared with 4 digits for the original system. The poorer resolution is simply due to the exhaustion of all available input lines on the KIM microcomputer. As a result the maximum measurable aerosol concentration for the smallest size intervals is decreased by a factor of approximately 5. In applications where this effect is a serious problem the DVM can be operated on the next decade larger scale to restore the high concentration capability of the original system. Although the program may be easily adapted to this case, the measurement accuracy of the largest size intervals will be diminished.

Secondly, the microcomputer addition in no way corrects those deficiencies of the EAA inherent in the physics of the device. In particular it is well known that the finite resolution (or "cross sensitivity") of the device can substantially distort the measured aerosol size

distribution (Liu and Pui, 1975). The usual EAA data reduction algorithm, which is identical to that used in the microcomputer program, does not correct for this effect. A more sophisticated data reduction scheme for the EAA exists, but presently is better suited to a full-sized computer than to a microcomputer (Liu and Kapadia, 1977). It is reasonable to expect, however, that the next generation of microcomputer-modified aerosol instrumentation will perform such tasks.

The first extensive application of the system described in this paper occurred during Autumn 1978, as part of a major study of air pollution in Houston, Texas, the results of which will be published elsewhere.

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